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INVESTIGATING MAPPING TECHNIQUES FOR ELUCIDATING PROCESSES OCCURRING IN PYROTECHNIC FLAMES AND THEIR FLAME ANALOGS

Final Technical Report

by

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Prepared under Contract N00019-76-C-0510

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. ~~TITLE (and Subtitle)~~ (6) INVESTIGATING MAPPING TECHNIQUES FOR ELUCIDATING PROCESSES OCCURRING IN PYROTECHNIC FLAMES AND THEIR FLAME ANALOGS.		(9) 5. ~~TYPE OF REPORT & PERIOD COVERED~~ Final Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) M. Bonner Denton	(15)	8. CONTRACT OR GRANT NUMBER(s) N00019-76-C-0510 NEVV
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Chemistry University of Arizona Tucson, Arizona 85721		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS N00019-7T-PR-RK001 12/77
11. CONTROLLING OFFICE NAME AND ADDRESS Department of the Navy Naval Air Systems Command Washington, D.C. 20361	(11)	12. ~~REPORT DATE~~ Dec 77
		13. NUMBER OF PAGES (12) 27p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Our Resdident Representative Room 421-Space Science Bldg University of Arizona Tucson, AZ 85721		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

High Speed Mapping
Automated Mapping
Flame Spectra

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Studies into the implementation and use of computer automated high-speed mapping techniques are described. Considerations involved in the development of experimental hardware and software are discussed. Data is presented detailing the systems' present performance.

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ABSTRACT

Studies into the implementation and use of computer automated high-speed mapping techniques are described. Considerations involved in the development of experimental hardware and software are discussed. Data is presented detailing the systems' present performance.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation for the support of these investigations by the Naval Air Systems Command, AIR 310C under the technical guidance of Dr. H. Rosenwasser. I also would like to express great appreciation to Dr. B. Douda and his research group at the Naval Weapons Support Center, Crane, Indiana, for valuable advice. Considerable recognition is in order for the extensive efforts exerted by John Algeo, Scott Tilden and David Heine during the course of this project.

The study of the complex interactive nature of chemical reactions occurring in heterogeneous flame systems presents a challenging, but formidable, problem. The difficulties inherent in extracting useful information from such systems are often complicated by a high degree of spectroscopic noise and, in the case of pyrotechnic flames, the transient and optically dense nature of the system. One promising approach to gaining a meaningful insight into transient combustion processes involves the use of a computer automated experimental configuration to implement high-speed mapping of the desired flame species.

The important considerations which determine the type and speed of the optical scanner, readout electronics, and data acquisition software have been evaluated and considerable advances have been made in the development of data handling and display algorithms so that a maximum amount of useful information can be extracted from each study.

A variety of criteria were considered during the design stages. These included:

(1) Scan Speed
(2) Desired Number of Data Points
(3) Observation Region
(4) Photometric Accuracy
(5) Error Detection
(6) Experimental Flexibility
(7) Capability for Performance Upgrading

While a variety of successful low-speed flame mapping experiments

have been performed employing stepper motor techniques to position a flame in the optical view path of a monchromator (1-3), such approaches are not suitable for a high-speed system. A variety of optical scanning techniques were considered in regard to the required performance criteria.

FLAME MAPPING SYSTEM

The approach which has been pursued is based on a multi-faceted scanning mirror concept. Scanning systems based on multifaceted mirrors offer a reliable, relatively inexpensive approach for providing sufficient speed and spatial resolution for the task at hand. Radiation can subsequently be reflected onto the entrance slit of a monochromator to provide maps of intensity at a selected wavelength as a function of location. Other approaches, such as vidicons etc., were bypassed due to their cost, very limited dynamic range, limited wavelength response and inherent dependence on optical filters for wavelength isolation when operated in an X-Y spacially scanning mode.

Unfortunately scan mirrors having the desired geometry, are not available commercially, dictating custom fabrication. While this might at first appear to be an ambitious undertaking, problems associated with holding precise optical tolerances, both on the offset angle and radius for each mirror surface, can be easily sidestepped through the use of the proper software correction techniques. In effect, when an array of points is being translated into a map, the data values are assigned locations offset by the

required correction factors.

The system, which has been developed, is shown in Figures 1-4. The ten-facet scanning mirror employs 38 mm square mirrors. The first five facets are set at zero, one, two, three, and four degrees. The next five facets are set at half degree offsets, creating an "interlaced" raster format which can be utilized for increasing the effective scanning speed when necessary. A synchronization pulse is derived by deflecting the beam from a 1.5 mW helium-neon laser onto a photoconductive detector which has been suitably positioned and masked to receive the laser beam only during exact alignment with a single mirror. The signal from the biased photo cell is conditioned with a voltage comparator, converted to TTL logic levels, and used for all subsequent timing during each individual flame scan. Photons emitted by the various areas of the flame under study are sequentially reflected from the scan mirror onto a pinhole iris, 1.0 mm in diameter, placed in front of the monochromator entrance slit. The 350 mm focal length f/6.8 GCA McPherson EU700 monochromator equipped with a 1180 l/mm 5000 Å blazed grating provides resolution of approximately 0.5 Å. Presently, a R212UH photomultiplier tube is mounted in a Pacific Photometric Instrument housing containing an integral high-speed preamplifier which can be either employed or bypassed at the operator's desire.

The signal is subsequently fed to a modified Keithley Instruments Model 417 high-speed picoammeter whose output signal is digitized under computer command with a Burr Brown Research Model

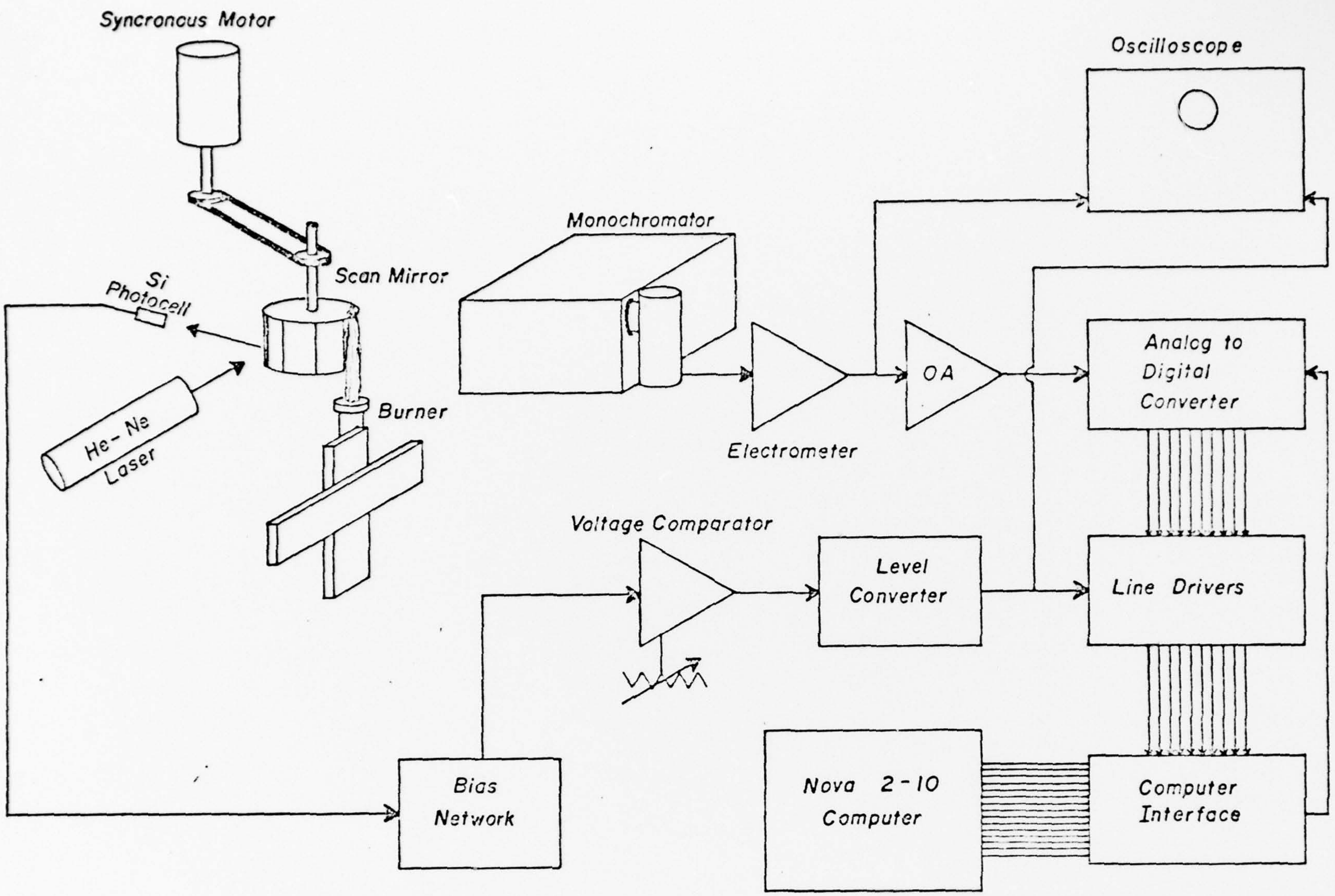


Figure 1: Diagram of the High Speed Flame Mapping System.

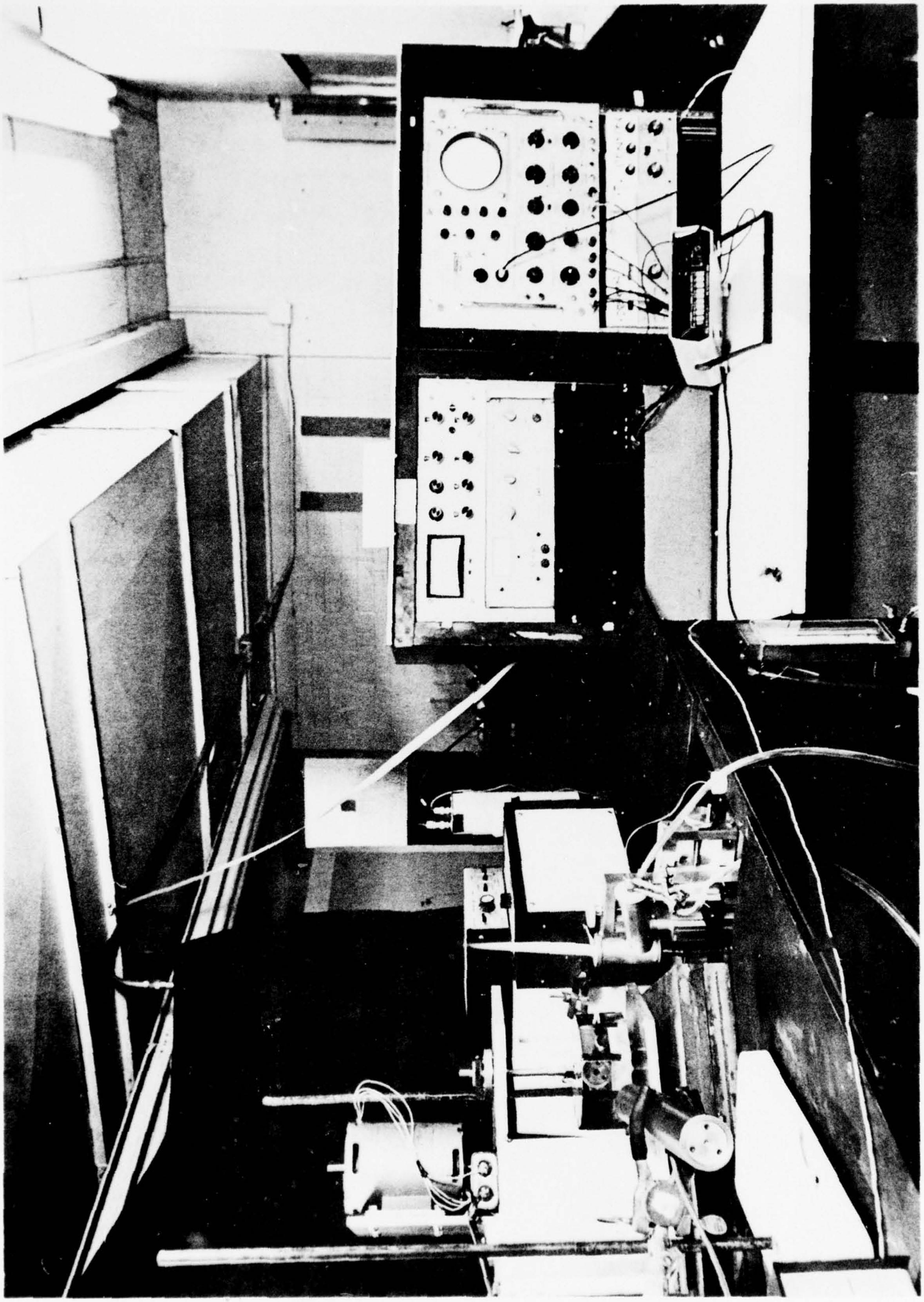


Figure 2: Overall Photograph of the High Speed Flame Mapping System.

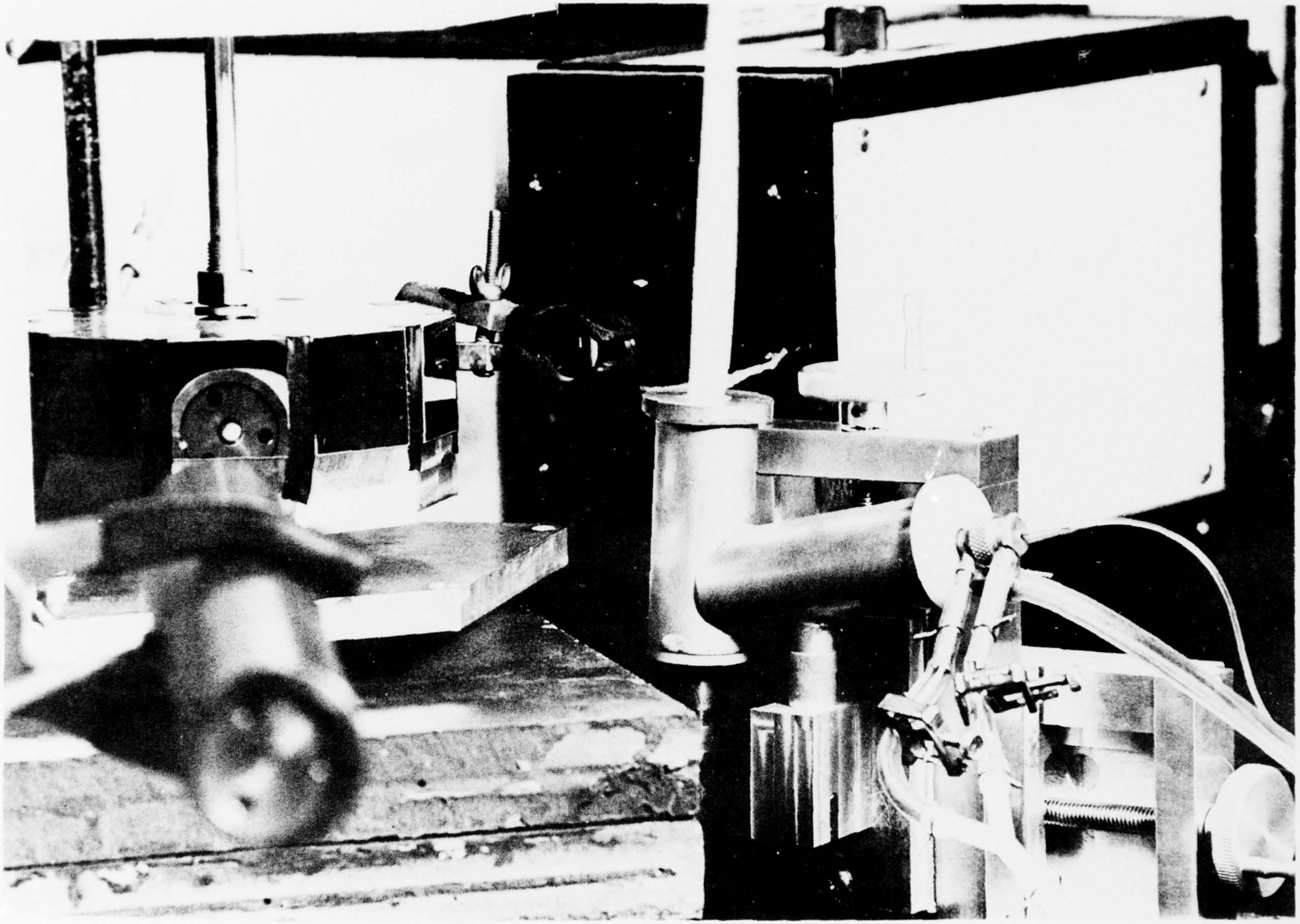


Figure 3: Close-up Photograph of the Optical Table Showing Scan Mirror, Flame Monochromator, etc. (Note: helium neon laser used for synchronization can be seen as a reflection in one of the mirror facets.)

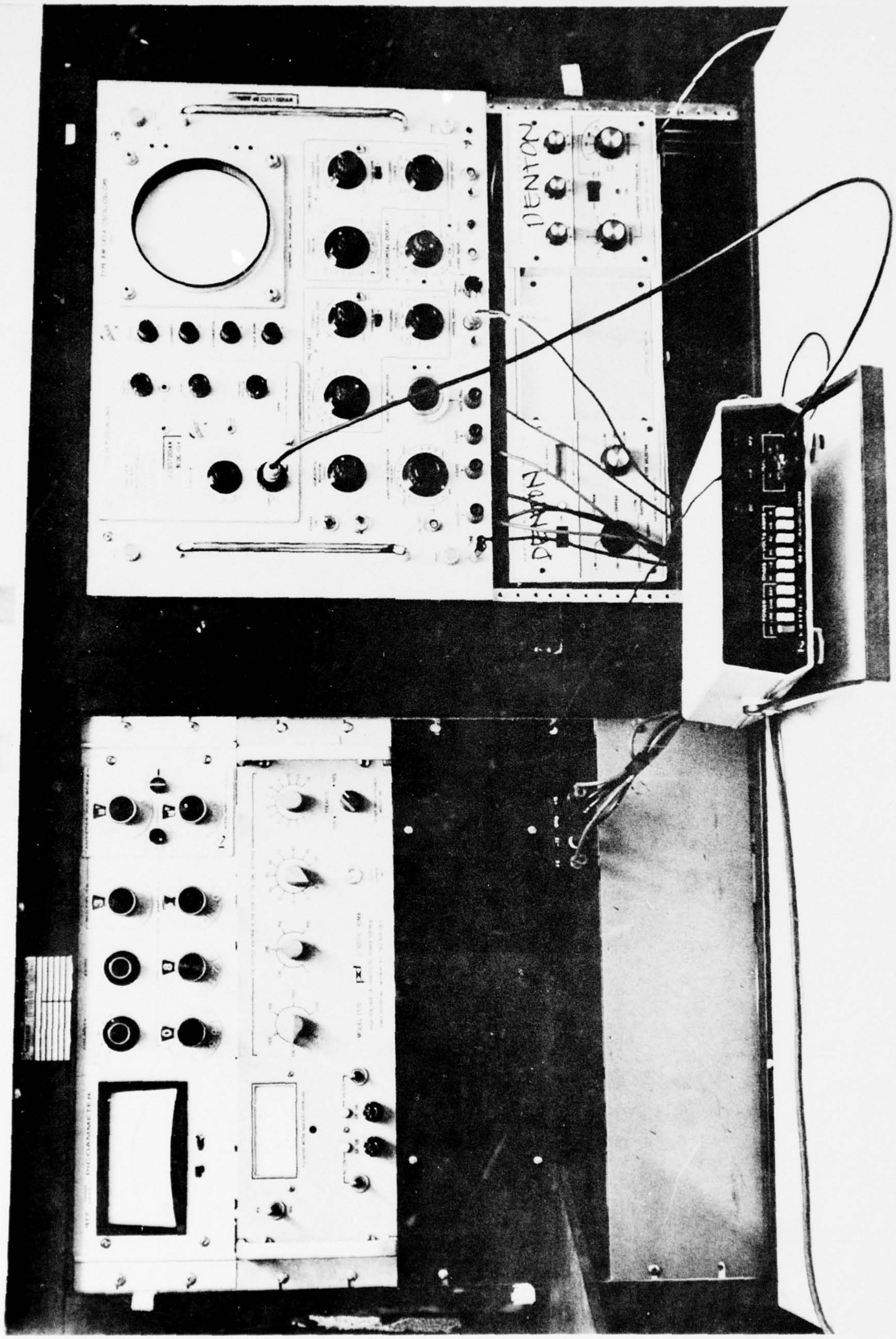


Figure 4: Close-up of the Electronics Console.

ADC-80 high-speed (20 usec/data point), ten bit resolution, analog to digital converter. Analog display is provided by a Tektronix RM585A oscilloscope equipped with a type 86 high speed plug-in. The output of the analog to digital converter is subsequently transferred through a set of parallel line drivers to a special computer interface and finally a Data General NOVA 2-10 computer containing 16K words of memory. Mass data and software storage is provided by a Xebec XFD-200 dual drive disc system, while plotting is performed by either a Tektronix 4010 graphics terminal or Hewlett-Packard-Moseley Model 135 X-Y plotter.

DATA MANIPULATION

Computerized data reduction can provide a variety of capabilities which would not be possible utilizing less powerful approaches. In addition to reducing the mechanical tolerances required for the rotating mirror assembly, problems associated with varying mirror reflectivity can be eliminated through employing the proper correction factors. The very serious problem of short term "flicker" noise can be substantially reduced using weighted smoothing techniques in both time and space. Consider that a single data grid is obtained containing randomly high and low values. A response surface can be smoothed considerably by employing a weighted average of each of the neighboring grid points. When the system is being scanned at a rate sufficiently faster than the rate of change of the phenomena under study, additional smoothing can be obtained by fitting a function to

the response observed at a certain location as a weighted average based on time. This procedure is diagrammed in Figure 5. A smoothed time extrapolated series of maps can subsequently be generated on demand. Additionally, when it is valid to assume that the flame under study is symmetrical about its vertical axis, equivalent points on each side can either be simply averaged together or used in some more complex statistical treatment.

The presence of phenomena occurring on time scales faster than the total scan speed can be detected in two ways:

1. Comparing the signals observed from two adjacent mirrors (which are offset one degree) with that observed from the intermediate angle mirror on the opposite side of the scanner, can be useful for determining the presence of transients on time scales near the total scan speed. Figure 6A shows the absence of major changes as angles of 0 degrees and 1 degrees are compared with 0.5 degrees following a 100 millisecond delay, while 6B indicates short term variation.
2. For vertically symmetrical systems, transients on time scales near a single horizontal scan can be detected by comparing the right hand side with the left hand side.

The ability to generate three-dimensional flame maps can provide considerable additional insight into flame processes. Unfortunately, the technique can only be applied when the flame system is sufficiently symmetrical and transparent. While these requirements are not met during combustion of many pyrotechnic devices, the approach can be very useful for developing a

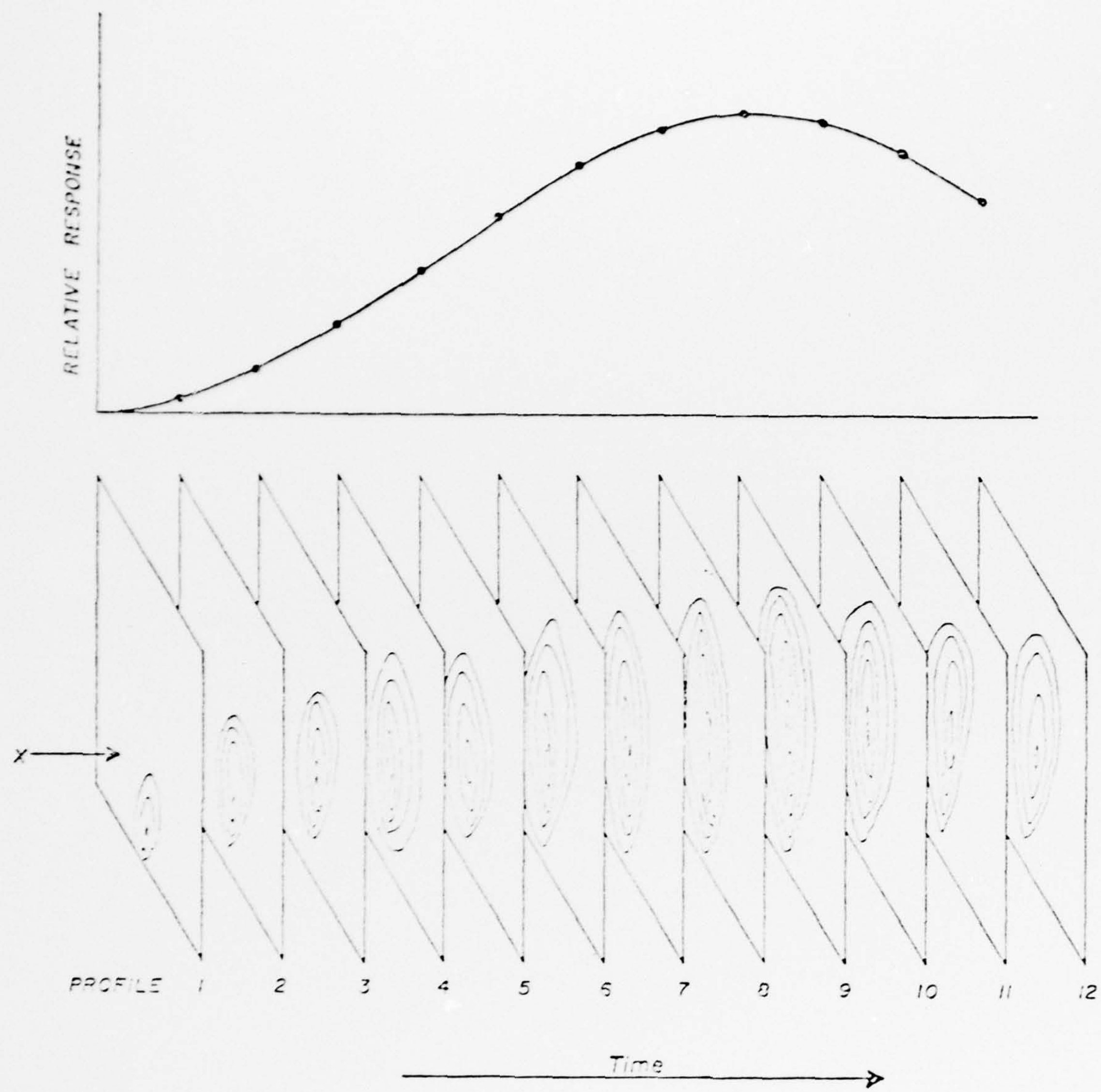


Figure 5: The Concept of Data Smoothing in Time by Curve Fitting to data obtained at a single location, X, to generate the smoothed curve above. (Curves of this type are then employed to generate each of the "smoothed maps".)

Figure 6A: Transient Phenomenon Occurring Much Slower than Total Scan Speed. (Note Signal at M_6 is between that observed at mirrors M_1 and M_2.)

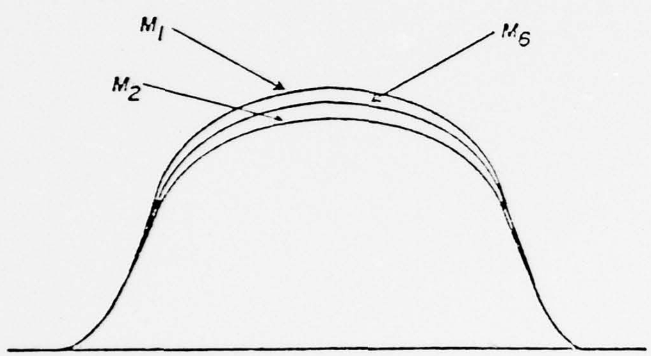
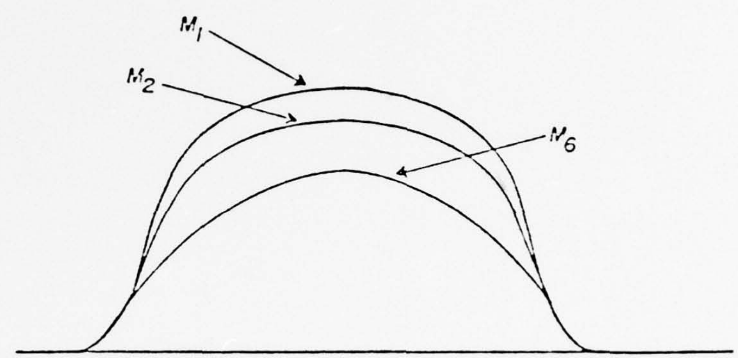


Figure 6B: Transient Phenomenon Occurring on Time Scale of one Half Scan. (Note signal at M_6 much different than M_1 or M_2.)



better understanding of a variety of combustion processes. An inverted Abel integral (4-8) is used to approximate the flame at any one vertical height as a set of symmetrical circles (see Figure 7).

During a scan at a single height, a measurement is initially made at position 1 through the outer circle and the presence of the observed species in region A is evaluated (see Figure 8). An observation is next made at location 2, which, following a correction for the contribution made by the amount of region A observed, yields the signal due to region B, etc. Continuation of this approach allows observation of the processes in the other regions. Several major problems arise when this simplified approach is used even in environments where self-absorption is not significant due to the relative noise inherent in spectral data. The noise problems have been adequately solved using an approach which has grown out of the method developed by Cremers and Binkebak (7). Techniques for correcting self-absorption are currently being developed using a combination of emission and absorption profiles.

CURRENT AND FUTURE STUDIES

The experimental system is currently able to generate either 600 data point maps every 150 milliseconds or 300 data maps every 75 milliseconds. Examples of such maps are shown in Figures 9-14. Additionally, scan speeds of 33 milliseconds and 16.5 milliseconds are to be implemented in the near future. The current principle limitation is that the high-speed memory

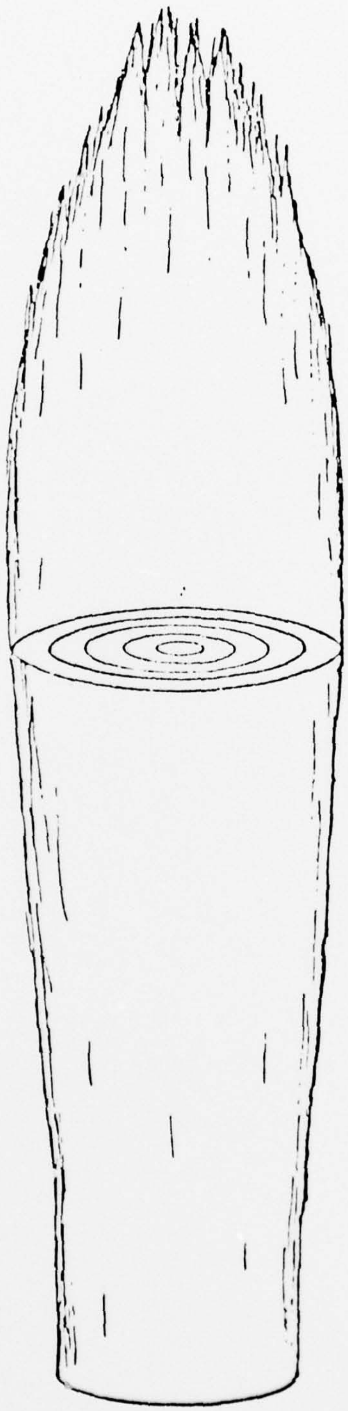


Figure 7: A Vertically Symmetrical Flame is Approximated by a Series of Circles.

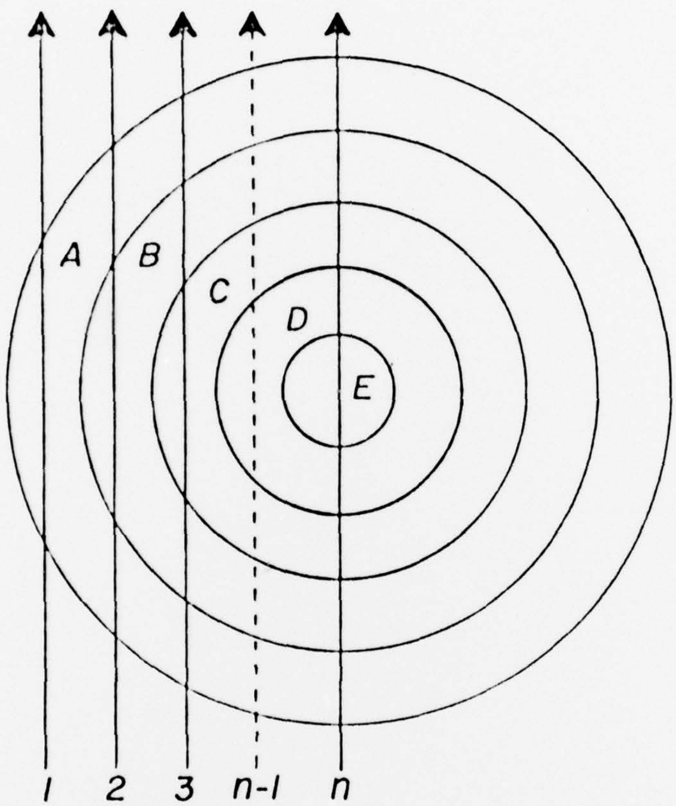


Figure 8: A horizontal slice through a circular symmetrical flame can be represented by a series of concentric circular regions.

available in the computer is very rapidly filled with data, severely limiting the number of maps which can be acquired.

Considerable progress has also been made toward developing improved algorithms for obtaining three-dimensional profiles on a variety of flame systems using both low-speed and high-speed mapping. Present capabilities for obtaining high-speed three-dimensional maps in spectroscopically noisy flames are shown in Figures 11-14.

SUMMARY OF EFFORT

The principal objectives of this project, to design and develop capabilities for obtaining combustion and excitation data from flame systems on a time scale compatable with pyrotechnic flares have been achieved and the next phase, actually mapping pyrotechnic flares, is ready to begin. The total number of direct labor man hours including principal investigator, three graduate assistants and other support personnel has exceeded 1600 hours. All Naval Air Systems Command funds have been spent.

The progress achieved within this period indicates the high potential inherent in extending the observed spectral region into the infrared and reconfiguring the system for studying actual pyrotechnic flares.

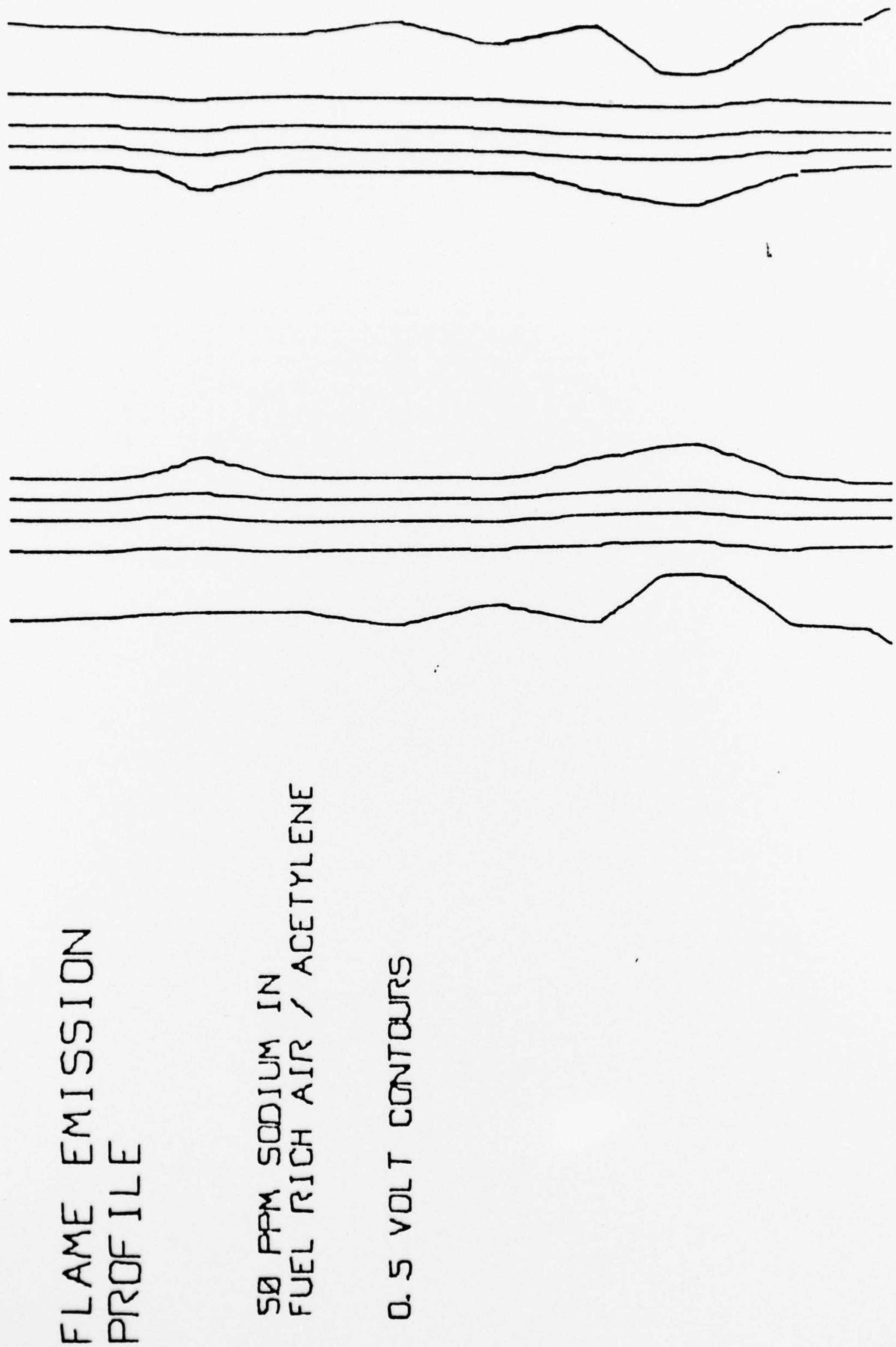

FLAME EMISSION
PROFILE
50 PPM SODIUM IN
FUEL RICH AIR / ACETYLENE
0.5 VOLT CONTOURS

Figure 9

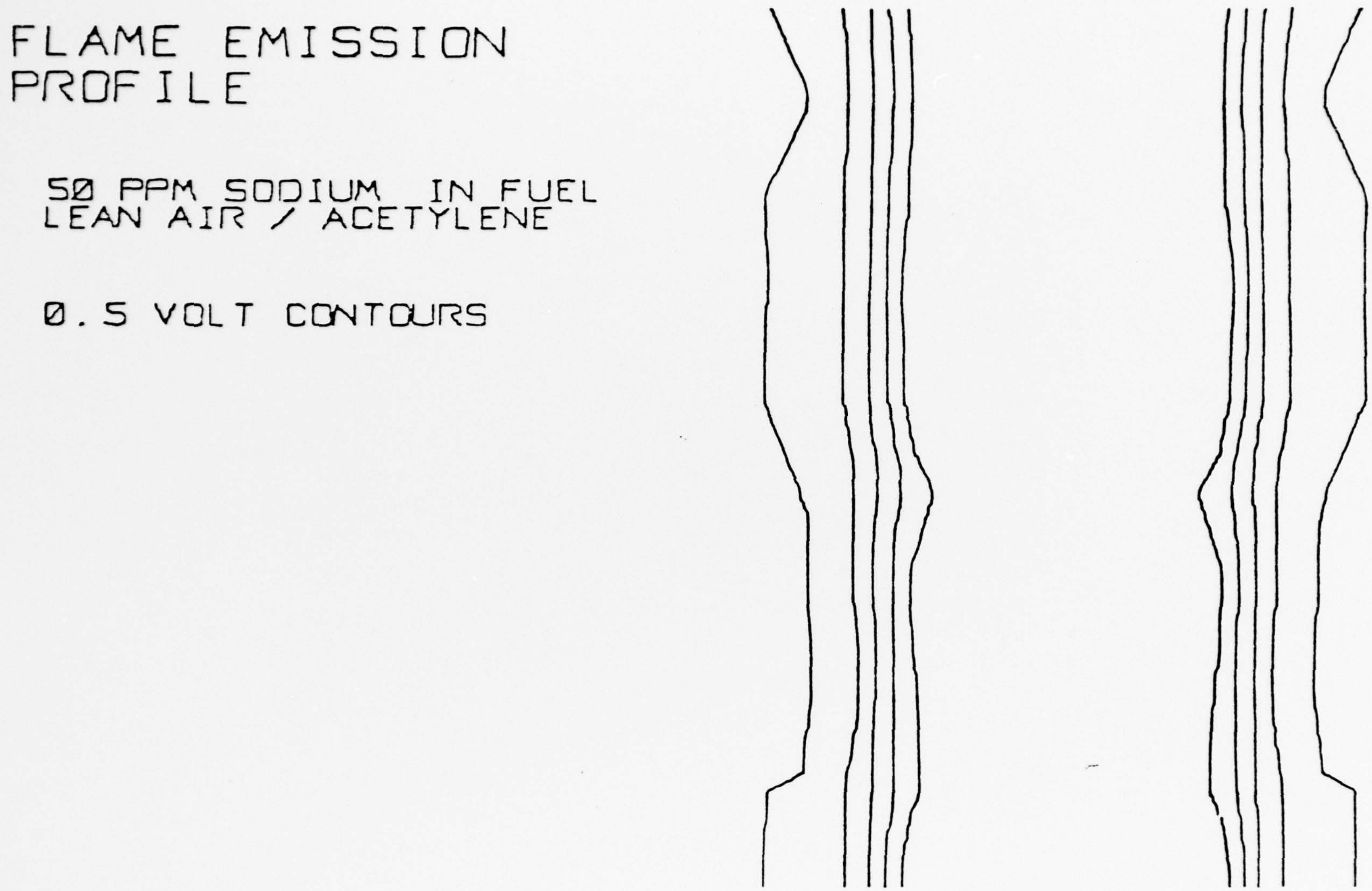
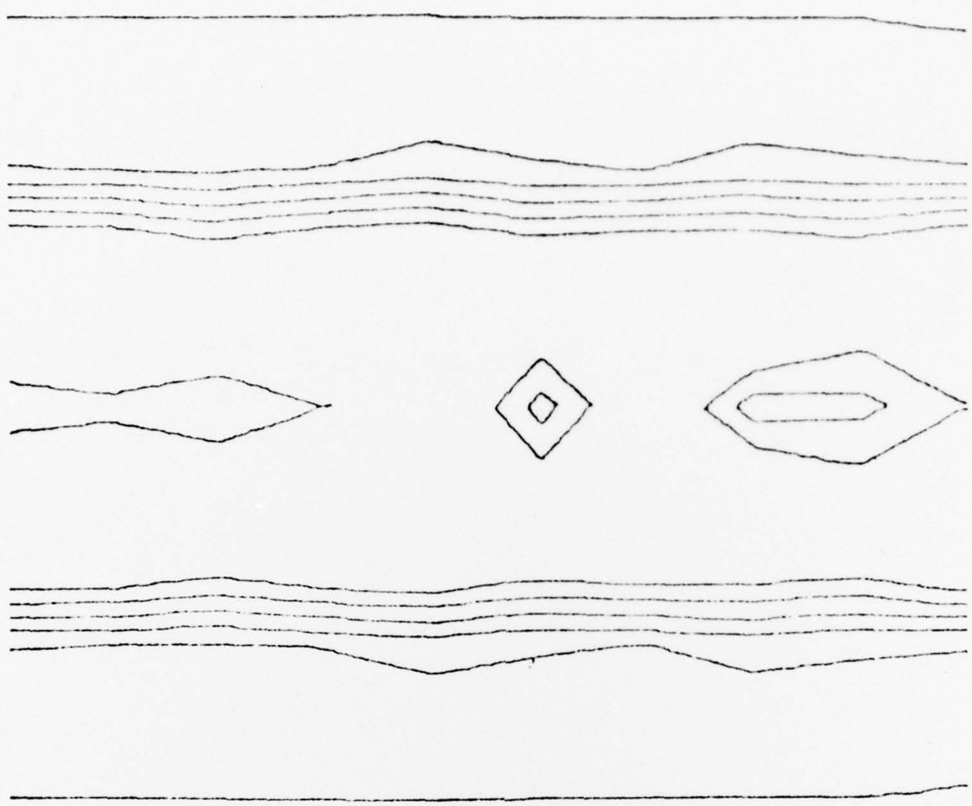

FLAME EMISSION
PROFILE
5Ø PPM SODIUM IN FUEL
LEAN AIR / ACETYLENE
Ø.5 VOLT CONTOURS

Figure 10



FLAME EMISSION
ABEL CORRECTED

5Ø PPM SODIUM IN FUEL
LEAN AIR / ACETYLENE

Figure 11

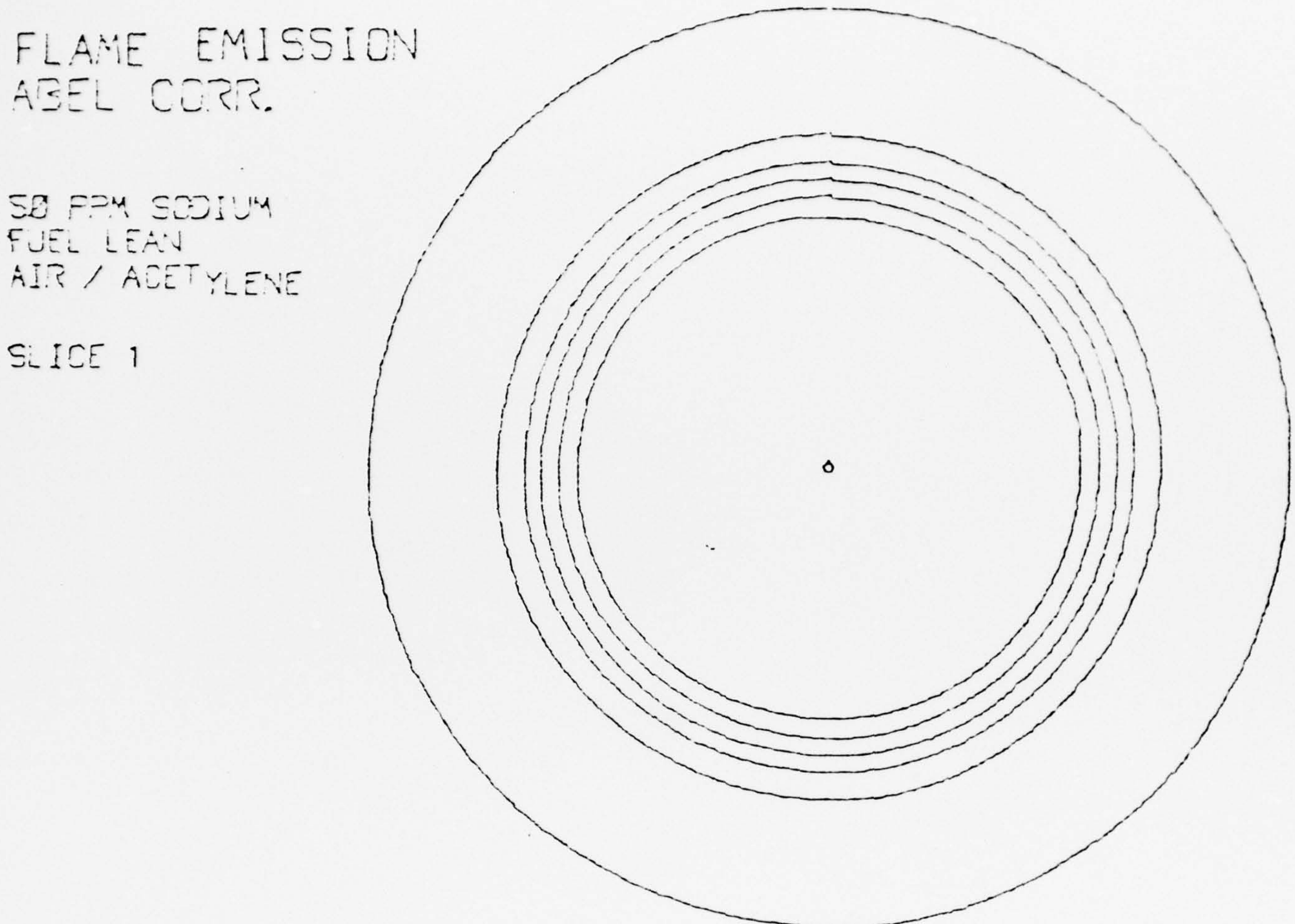

FLAME EMISSION
ABEL CORR.
5Ø PPM SODIUM
FUEL LEAN
AIR / ACETYLENE
SLICE 1

Figure 12

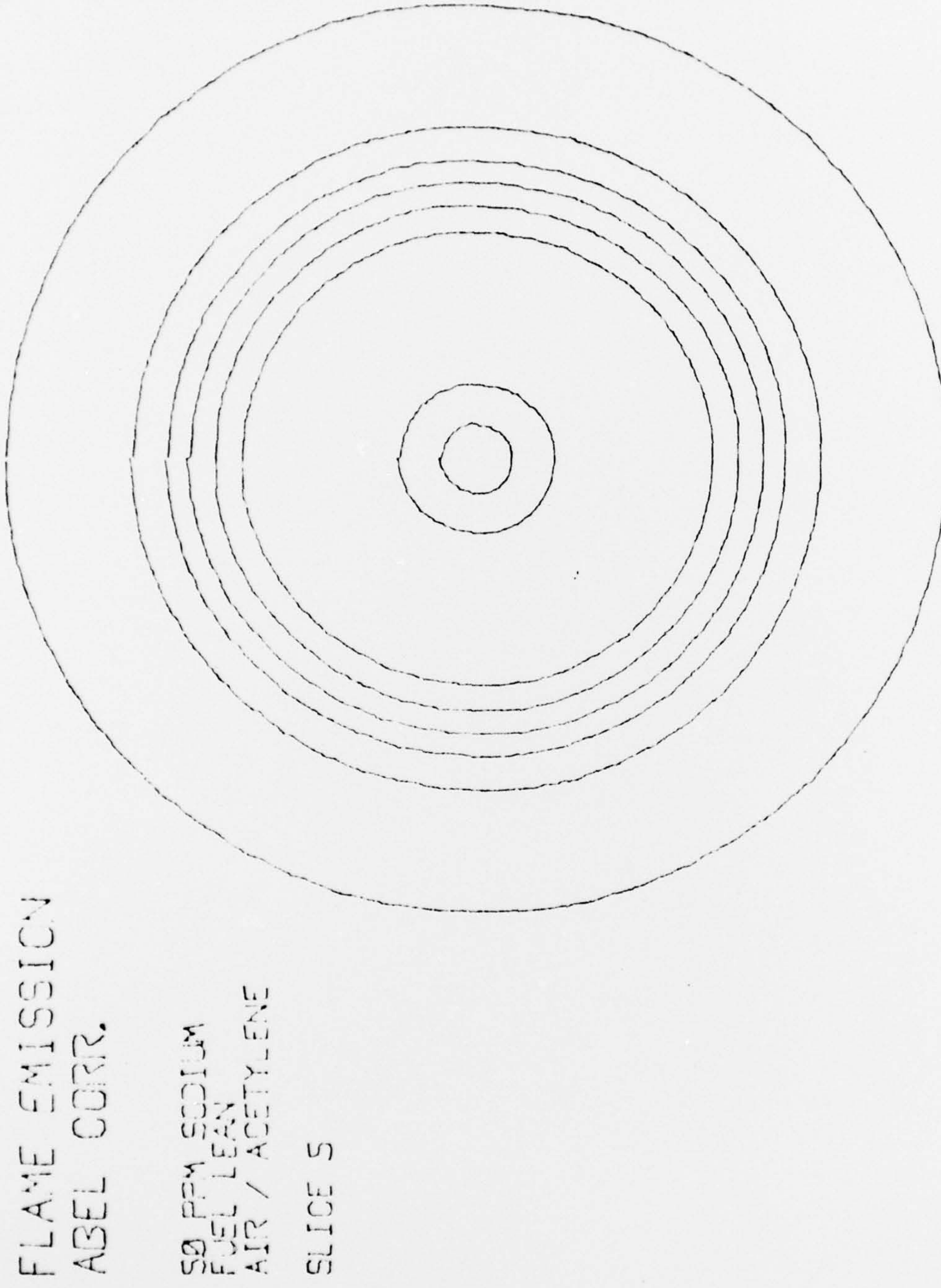

FLAME EMISSION
ABEL CORR.
50 PPM SODIUM
FUEL LEAN
AIR / ACETYLENE
SLICE 5

Figure 13

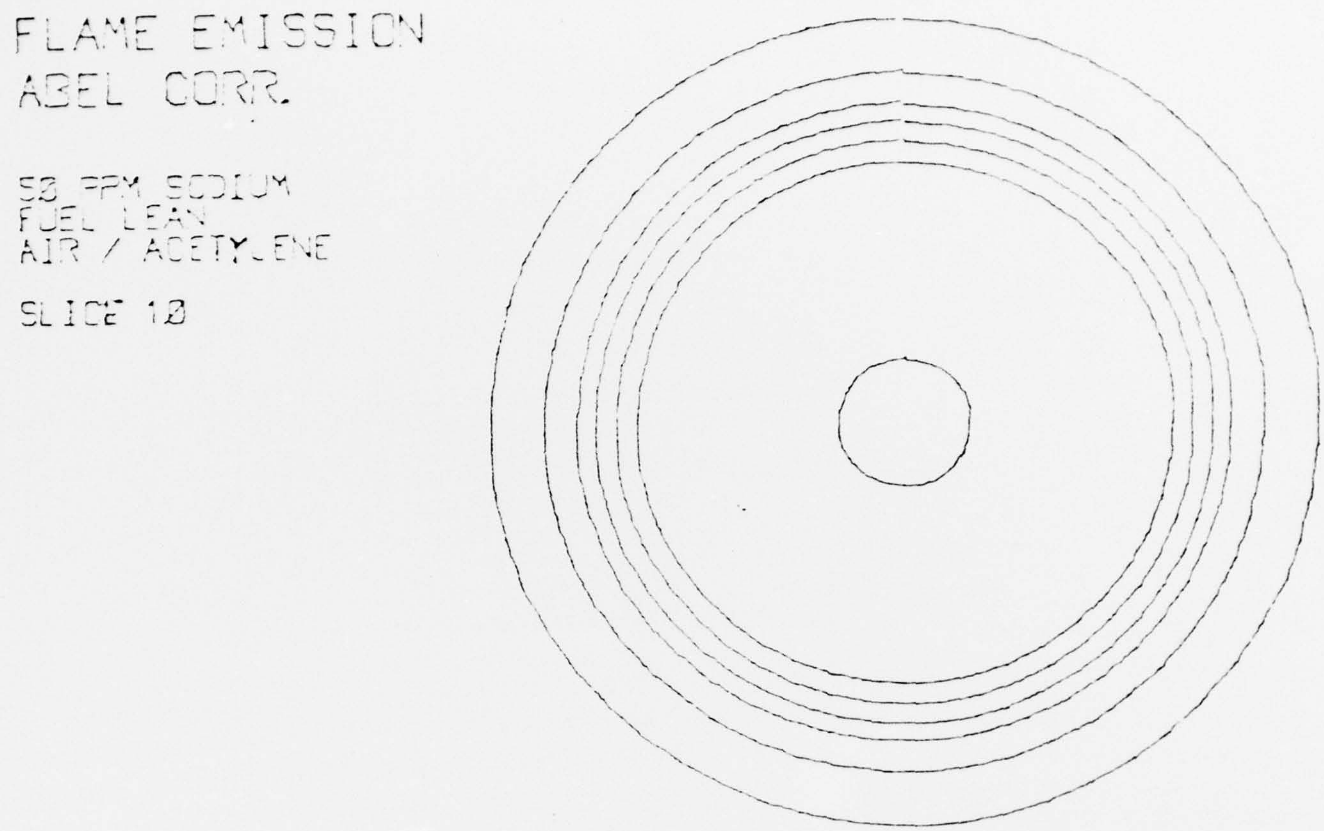

FLAME EMISSION
ABEL CORR.
50 PPM SODIUM
FUEL LEAN
AIR / ACETYLENE
SLICE 10

Figure 14

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